Clinical Application for Assistive Engineering – Mixed Reality Rehabilitation

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Abstract

Mixed reality (MR) is a collective term for technologies that merge the real and the virtual. In medical applications of MR technologies, research is in progress for applications in surgical procedure simulation systems designed for therapy and medical training and increasing proficiency in fields such as ophthalmology, brain surgery, and orthopedic surgery. MR rehabilitation holds the potential for substantial advances and contributions in respect to therapeutic efficiency, recovery from psychosomatic disorders, and heightening of patient desire, motivation, and acceptance through the patient’s own appraisal of physical and mental disability. This study focused on the development of a medical device system using a head mounted display (HMD) for examination and treatment of the visuospatial cognitive disorder known as unilateral spatial neglect as an illustration of MR rehabilitation.

Keywords: Head mounted display (HMD), Unilateral spatial neglect (USN), Mixed reality rehabilitation

1. Introduction

Mixed reality (MR) is a collective term for technologies combining the real and the virtual. It encompasses augmented reality (AR), in which computer graphic (CG), alphanumeric, or other forms of information are superposed on the actual field of vision, and augmented virtuality (AV), in which real-world information is superposed on a virtual space in the computer. Research and development in MR technologies includes “3D spatial synthesis”, which seamlessly entrains and fuses photographic images in 3D computer images, small, light, transparent HMDs, and display devices. The display devices provide a brightness and field of vision approximating those of the natural environment and affect the sense of balance and other perceptions while avoiding adverse effects.

In medical applications, research is in progress for applications in surgical procedure simulation systems designed for therapy and medical training and increasing proficiency in fields such as ophthalmology, brain surgery, and orthopedic surgery, and for applications serving human information and psychological needs, such as psychosomatic anxiety analysis and anxiety-relief training, and support of relaxation for recovery from stress and mental fatigue. For applications in cognitive science, research has begun on human perception and response to stimulations using MR technology to provide presentations for perception and cognition. In our study, research based on motor learning theory has begun for utilization of MR technologies in what is termed “mixed reality rehabilitation” in certain fields of rehabilitation, in which the patient receives various forms of biofeedback (auditory, visual, and somatosensory inputs). MR rehabilitation holds the potential for substantial advances and contributions with regard to therapeutic efficiency, recovery from psychosomatic disorders, and heightening of patient desire, motivation, and acceptance through the patient’s own appraisal of physical and mental disability.

This paper focused on the development of a medical device system using a head mounted display (HMD) for examination and treatment of the visuospatial cognitive disorder known as unilateral spatial neglect (USN) as an illustration of MR rehabilitation. USN is a common syndrome in which a patient fails to report or respond to stimulation from the side of space opposite a brain lesion, where these symptoms are not due to primary sensory or motor deficits [1]. Patients with severe neglect often collide with objects, ignore food on one side of the plate, and in general tend to rely on just one side of the body [2]. Patients with USN of the left hemispace require longer hospital stays and have more difficulty resuming activities of daily living [3]. Neglect is associated with lower performance on measures of impairment, as well as on measures of disability in ADL. Recently, several studies have singled out USN as one of the major disruptive factors impeding functional recovery and rehabilitation success [4].

From a rehabilitation perspective, the traditional assessment of USN centers on a variety of simple perceptual motor tasks. Investigations have used line crossing [5], cancellation task [6] and more recently, an indented reading
test [7]. However, there is no single standardized battery of tests currently available for the assessment of USN.

An analysis of USN can be explained with a space coordinate system theory. The boundaries of the neglected space are not constant in as much as the neglect patients’ performance is influenced by the relevant system of spatial coordinates; egocentric or allocentric co-ordinates. Egocentric co-ordinates specify locations relative to the viewer [8,9], whereas allocentric co-ordinates code their position independent of viewpoint [10].

Several sensory manipulations may be temporarily effective for improving unilateral spatial neglect. Karnath indicated the effectiveness of neck vibration [8,9]. Pizzamiglio et al. [11] also adopted an effective means of optokinetic stimulation. Rossetti et al. [12] investigated the effect of prism adaptation on neglect symptoms, including the pathological shift of the subjective midline to the right. They reported that all patients exposed to the optical shift of the visual field to the right were improved in their manual body-midline demonstration and on their classical neuropsychological tests. However, these manipulations have not yet succeeded in bringing about a consistent improvement of neglect.

Virtual reality (VR) has many advantages over other ADL rehabilitation techniques and offers the potential to develop a human performance testing and training environment [13] and also a VR system for training individuals with unilateral spatial neglect to cross streets in a safe and vigilant manner [14]. VR can give human versatile sensory information artificially and easily for the visual, vestibular, and the somatic sensations. Recently, VR has been investigated in a few studies using devices for compensation of visual sensory. For example, there is one approach where HMD gives a patient with Parkinson’ disease an emphasized visual input in order to improve a frozen gait of the patient [15]. HMD has a function which can focus on a certain object or to limit the surrounding environmental conditions, and to offer versatile visual information. Therefore, HMD can produce object-centered co-ordinates for a USN patient.

The purpose of this study was to analyze an evaluation process system of USN using HMD in order to understand more accurately any faults of USN operating in the object-centered coordinate and egocentric co-ordinate systems.

2. Methods

2.1 Subjects

Nine patients who had suffered a stroke (mean age 68.7 years old) participated in this study after giving their informed consent. The patients were tested for the presence of any neglect for activities of daily living (ADL) by two physical therapists. Two medical doctors checked the right hemisphere damage of all subjects by computed tomography (CT) or magnetic resonance imaging (MRI). Individuals with weak visual acuity, dementia, hemianopsia, apraxia or those who were left-handed were excluded. The subjects also had to be able to sit on an ordinary chair by themselves. The period from the appearance of disease to study assessment was 4-27 weeks (Table 1).

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Age (years)</th>
<th>Diagnosis</th>
<th>Lesion</th>
<th>Time of rehabilitation onset (weeks)</th>
<th>FIM-M</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>75</td>
<td>FPT</td>
<td>6</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>65</td>
<td>BgFPT</td>
<td>1</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>64</td>
<td>H</td>
<td>1</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>63</td>
<td>Th</td>
<td>1</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>56</td>
<td>PT</td>
<td>1</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>70</td>
<td>Bg</td>
<td>1</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>79</td>
<td>FPT</td>
<td>1</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>68</td>
<td>BgFPT</td>
<td>2</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>78</td>
<td>PT</td>
<td>1</td>
<td>42</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: I, infarction; H, hemorrhage; F, frontal lobe; P, parietal lobe; T, temporal lobe; Bg, basal ganglia; Th, thalamus; FIM-M, functional independence measure motor.

*All lesions were right sided.

2.2 Functional assessment

The Functional Independence Measure (FIM) was executed as an ADL evaluation [16,17]. The FIM motor sub scores (FIM-M) were used for measure of disability as the best predictors of rehabilitation length of stay for stroke. Moreover, two physical therapists evaluated the patients who exhibited specific neglect behaviors in ADL using a special checklist (Table 2). A modified version of Halligan’s checklist was used [18]. The therapists were requested to score the checklist in terms of those behaviors they considered to be related to visual neglect, as opposed to poor performance that might be expected to follow concomitant disorders such as problems of motor coordination or initiation.

<table>
<thead>
<tr>
<th>Table 2. Checklist of everyday neglect behaviors.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Does the patient show difficulties when talking or communicating with others?</td>
</tr>
<tr>
<td>2. Does the patient neglect the left/right side of personal space?</td>
</tr>
<tr>
<td>3. Does the patient show difficulties in eating?</td>
</tr>
<tr>
<td>4. Does the patient show difficulties in grooming (self-care skills, washing, bathing, etc.)?</td>
</tr>
<tr>
<td>5. Does the patient show difficulties in dressing?</td>
</tr>
<tr>
<td>6. Does the patient show difficulties in body movement transferring (from a bed to W/C, etc.)?</td>
</tr>
<tr>
<td>7. Does the patient show difficulties in locomotion 1 (the patient collides against objects and wall on the affected side; the patient can not negotiate a W/C between doors, kerbs, etc.)?</td>
</tr>
<tr>
<td>8. Does the patient show difficulties in locomotion 2 (the patient turns toward the direction of the affected side)?</td>
</tr>
<tr>
<td>9. Does the patient show difficulties during PT exercise?</td>
</tr>
<tr>
<td>10. Does the patient show difficulties during OT exercise?</td>
</tr>
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2.3 Evaluation for USN

2.3.1 Common clinical test

To assess neglect, the widely used line and star cancellation tests as included in the Behavioral Inattention Test (BIT) were given to the subjects [19]. We used the BIT Japanese version which was modified by Ishi et al [20].

For the line cancellation test (score range from 0 to 36 points), the subjects were presented with a single sheet of paper on which 6 lines in varying orientations were drawn,
18 on each side (Fig. 1). They were instructed to make a mark through all of the lines. Left-sided neglect was indicated by a failure to mark more lines on the left side than on the right. Degree of neglect was assessed by the proportion of lines omitted relative to the total number of lines. The line cancellation test sheet was divided into right and left portions and a right and then a left correct answer rates were analyzed. Thirty-four points were set as a cutoff value.

Special test 2: the zoom-out (ZO) condition, which could display 70 percent of the test sheet using combined HMD and a DV camera in the object-centered co-ordinate system.

Special test 3: the actual image condition (zero percent reduction), in which a combined HMD and a micro CCD camera simultaneously moved to follow the subject’s movement in the egocentric co-ordinate system.

2.3.2 Special test with HMD

The main experimental apparatus included a digital camera, HMD (GT270, Canon Inc.), and a digital video camera (Fig. 2). HMD is a glass-type display method (270,000 pixels, effective pixel number is 99.99%, weight is 150 g) that consists of two TFT liquid crystal panels. The digital camera takes a picture of a test sheet on the desk, and HMD presents the subject from the digital camera. Moreover, the subject’s head movement was recorded by a digital video camera as a qualitative motion analysis.

We attempted to find the degree that USN alters when the co-ordinate of the subject’s visual field was carried out as object-centered by HMD (Fig. 3). Therefore, we used two different lenses of the digital camera in order to change visual field and then an HMD displayed the test sheet to the subject as the three special tests as follows.

Special test 1: the zoom-in (ZI) condition, which could display only the test sheet using combined HMD and a DV camera in the object-centered co-ordinate system.
2.3.3 Procedure

The subjects sat on a wheelchair if needed or on a straight back chair sitting in an upright position as a starting point. The test sheet was put on a desk and was placed at a midline of each subject's body. All tasks were done without any restriction as to time.

Eight subjects (patients numbered from 1 to 8) performed the common clinical test and special tests 1 and 2 in Table 1. The subjects were first evaluated by a common clinical test without HMD and then two spatial tests with HMD. The line cancellation test was scored using the correct rate and then the score was divided into two areas: right and left. The star cancellation test was scored using the correct rate for six areas (left-left, middle-left, right-left areas and right-right, middle-right, left-right areas) in which the test sheet was divided (Fig. 1). The eight subjects performed in random order the common clinical test and two special tests (special test 1 and 2).

The examiner confirmed the HMD monitor as the display from the image of the digital camera. Moreover, one subject (patient number 9) performed the common clinical test and two special tests, special test 1 and 3, in both object-centered and egocentric co-ordinate systems (Table 1).

2.3.4 Data analysis

All statistics were performed using SPSS statistical software (16.0J). An ANOVA or Student's t test was used to compare the common clinical test and the two special tests with HMD. Moreover, a Student's t test or an ANOVA was used for a comparison within the line cancellation test and the star cancellation test, respectively. Multivariate ANOVA tests were performed in each group and Shiefe post hoc tests were performed if significant differences were found at the 5% significance level.

3. Results

According to the result of FIM-M score in Table 1, the degrees of dependency of subjects were range from maximal assistance to modified independence. However, their degrees of dependency were range from minimal assistance to modified independence when the subject was sitting position.

Figures 4-8 display data of the eight subjects (Patients No. 1-8). As the common clinical test for USN, in the first evaluation of the frequency of presence of neglect for ADL (Fig. 4), 75 percent of all subjects admitted a USN symptom in activities of dressing. For example, a patient with USN cannot easily put on their clothes on the left side. Moreover, 62.5 percent of the subjects admitted a USN symptom in activities of transferring, and locomotion (Fig. 4). According to the motion analysis of head motion in the common clinical test, the subjects began searching from the right side in both the line and the star cancellation tests. In a normal performance, the head naturally rotated from the right to the left to follow a movement during the line cancellation test. However, the head movement to their left was insufficient for searching from the right side in both tests. For the line cancellation test under the common condition, the mean percentage of the correct answers at the left side in the test sheet was 94.4%. The right side was 100%.

Nobody fell below the cutoff value (Fig. 5) [20]. For the star cancellation test under the common clinical test (Fig. 6), the mean percentage of the correct answers at the left-left area was 91.1%. The middle-left area was 89.2%, and the right-left side was 84.4%. The mean percentage of the correct answers in the right-right area was 92.9%, middle-right was 96.4%, and left-right area was 81.8%. Three subjects fell below the cutoff value as abnormal results [20].
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4. Discussion

The correct answer rate of the left space under ZI and ZO conditions was significantly lower than those in the common clinical test. Moreover, the correct answer rate, which rose under ZO condition was slightly greater than that under ZI condition. It might be considered that ZI condition placed a greater focus on an object than did ZO condition. These results indicated that when the patients with USN concentrated on an object, their USN symptoms were more aggravated. The subjects’ dressing, transferring, and locomotion of checklist by Halligan et al. [18] indicated a high percentage of presence of USN symptoms. Although the common BIT did not sufficiently show USN where the correct answer rates score of the left space was more than 80%, the special test with HMD indicated USN where the correct answer rates score of the left space was about 60%. The HMD test may be able to better find a USN symptom which may not be easily discovered by the common clinical test.

In our previous study, the use of the HMD improved the neglect symptoms in all subjects who had right cerebral hemisphere damage [21]. Rossetti et al. [12] investigated the effect of prism adaptation on neglect symptoms, including the pathological shift of the subjective midline to the right. They reported that all patients exposed to the optical shift of the visual field to the right were improved in their manual body-midline demonstration and on their classical neuropsychological tests. Lee et al. [22], Woo and Mandelmant [23] also suggested the effectiveness of the Fresnel prism when placed on a spectacle lens for improving various visual-field losses. The improvement induced by the HMD indicates that a signal is given to the brain that stimulates the natural recovery process in the same manner as the prism adaptation method. Moreover, the HMD system may lead to further correction of left neglect compared with that by a Fresnel prism placed on a spectacle lens. Since a high-power Fresnel prism membrane for obtaining a wide field of view is not clear, the prism produces a distortion of a real image and has lowered capabilities of visual acuity. By contrast, the HMD has the possibility of obtaining various fields of view without deterioration of visual acuity.

The HMD system may play an important role in the neuropsychological rehabilitation of unilateral spatial neglect as an evaluation device. Bowen et al. [24] performed a systematic review of published reports. They found 17 reports which directly compared right brain damage (RBD) and left brain damage (LBD), and USN occurred more frequently after RBD than LBD, as supported by a systematic review of the published data. However, an accurate estimate of the rates of occurrence and recovery after stroke could not be derived. They suggested that different USN disorders may exist, which may require type-specific rehabilitation approaches. Our system may have clinical implication for new assessment because HMD can change versatile visual input to fit each patient’s degree of USN, because a clinical assessment for USN may be able to use various images in HMD by a computer, such as change of colors and partial enlargement or reduction of real image, and to produce suitable visual information in HMD for each patient who has USN.
The result also showed that HMD evaluation could produce the condition of object-centered allocentric co-ordinate and egocentric co-ordinate systems to clarify the left neglect area which can not be easily observed in the clinical evaluation for USN.

5. Conclusion and future development

It is possible to design an HMD for viewing by both eyes, and we hope to achieve this to provide greater depth perception and thereby enable richer, fuller, three-dimensional observation. Continuing development of MR technology also holds great promise for resolution of ethical issues relating to medical research and practice. In many areas where medical research is currently difficult or impossible because of ethical considerations, developments in MR technology will make it possible to test hypotheses and investigate the feasibility of medical therapies. For illustration, it is currently difficult to perform evaluation of postural and ambulatory control under the actual conditions of a complex environment, because of the burden on the test subject and the danger of falls and other possible injury. However, advanced MR systems could effectively eliminate these problems through preliminary simulation of the ADL in an environment specific to the individual, so that the subject could safely perceive the surrounding environment and the risk of falling, and thus help the patient to develop the capability for smooth performance in the actual living and working environment. A broad range of potential applications exists in MR rehabilitation and other supportive MR equipment and devices, not only in cases of spatial neglect but also in cases of speech, thought, memory, behavior, learning, and attention disorders due to partial brain damage.

In conclusion, the results showed that the assessment of USN using an HMD system may clarify the left neglect area which cannot be easily observed in the clinical evaluation for USN. Moreover, it might be hypothesized that the USN test using HMD may display a greater accuracy and be able to assess the occurrence and degree of USN to a greater degree more than the common clinical test. HMD can produce an artificially versatile environment as compared to the common clinical evaluation.

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References